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EVALUATION OF THE MULTIPATH EFFECT ON THE QUALITY OF RADIO COMMUNICATION IN THE TECHNOLOGICAL RANGE IEEE 802.11xx

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Background. As a result of the rays' reflection from buildings, from the surface of the Earth or from horizontal boundaries between different layers of the atmosphere, occur multipath effects that cause fast fading, which degrades the quality of service.

Objective. The purpose of the paper is to determine the multipath effect on the signal-to-noise ratio in a wireless communication channel. Compare the results obtained for a communication channel at operating frequencies of the IEEE 802.11xx standard: 5 GHz and 2.4 GHz.

Methods. The useful signal powers and the total interference powers for a communication channel with multipath are calculated. The signal-to-noise ratio for such a channel is compared at operating frequencies of 5 GHz and 2.4 GHz.

Results. The results of the study showed that the higher the frequency of the carrier of the wireless radio link, the less pronounced the effect of multipath is.

The frequency rating significantly affects the quality of communication in multipath conditions. In this case, lowering the frequency significantly improves the reception condition outside of multipath effect. However, it deteriorates significantly due to the effects of rays reflected from the Earth's surface.

In the considered case, the useful signal power in the 2.4 GHz band is 4.2 times higher; at the same time, the power of reflected interference is 19 times higher than in the 5 GHz band.

Conclusions. Suggested model makes it possible to determine the effect of interference power in the ranges traditionally assigned in IEEE 802.11xx technology, specifically 2.4 GHz and 5 GHz.

Keywords: *multipath; IEEE 802.11xx; Cassini Oval; OFDM.*

Introduction

IEEE 802.11 - a set of communication standards for communication in a wireless local area network area with frequency bands 0.9; 2.4; 3.6; 5 and 60 GHz. Wireless broadband technologies have been developed to provide services comparable to those of wired networks. Cellular networks now support high-bandwidth data transmission for many mobile users at the same time. In addition to this, they also provide mobility support for voice communication [1].

Wireless data networks can be divided into several types depending on their coverage area, such as [2]:

WLAN: Wireless local area network in an area with a cell radius of up to one hundred meters, mainly in home and office environments.

WMAN: wireless city network; usually cover wider areas, as large as entire cities.

WWAN: A wireless wide area network with a cell radius of about 50 km, covering areas larger than a city.

Formulation of the problem

In recent years, the rapid development of wireless communication technologies [3, 4] has radically changed our way of life. Compared to wired communication, a wireless communication channel is more complex [5]. Wireless channel limitations include limited bandwidth, multipath, Doppler shift and complex noise pollution, etc. First, intersymbol interference (ISI) caused by multipath increases the bit error rate (BER). Second, the Doppler shift generated by mobile terminals and scattered clusters results in time-varying channel properties[6].

Multipath propagation occurs when environmental conditions cause combinations of reflected and/or diffracted echoes to arrive at the receiving antenna. These signals, in combination with the original line-of-sight signal, can cause distortion of the correlation function of the receiver and, ultimately, the discrimination function and, consequently, errors in the range estimate [7].

Evaluation of spatial-time characteristics of a wireless communication channel

To understand the benefits of features of wireless communication channel usage, let's first consider an example of a simple wireless channel. Fig. 1 shows the transmission of a signal from a transmitter (let's call it point **A**) to a receiver (point $\mathbf{A_1}$). The receiver and transmitter are at a distance **R** from each other. The main signal comes to point $\mathbf{A_1}$. But at the same time, there is a response of the main signal, which passes the trajectory $\mathbf{R_2}$ and, reflected from a certain surface at point **B**, also comes to point $\mathbf{A_1}$. In this case, the response of the main signal will interfere with the useful signal. Will be assumed that the circle is the boundary, within which all signals that can be perceived at point $\mathbf{A_1}$ are located (at the same time, the radius of such a circle should be much less than the length of the trace). Will be considered that the signals that are reflected outside this circle are below the sensitivity of the receiver and are not perceived as reflected beams. It means that outside this area, obstacles and reflecting surfaces have no influence [8].

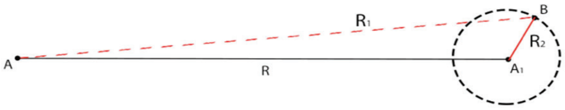

Fig. 1. Schematic representation of a communication line A-A_1 and a random reflected ray A-B-A_1

Then should be calculated the spatial characteristics of the channel ($\mathbf{R_1}$ and $\mathbf{R_2}$) using the parameters of the mobile communication line between the base station and the mobile subscriber. the trajectory outlined by the dotted line will be considered as the locus of points where the values of $\mathbf{R_1}$ and $\mathbf{R_2}$ are continuously changing, and their product remains a constant number (1):

$$R_1 R_2 = \sqrt{\frac{k_0 P_T G_T G_R \lambda^4 \eta_T \eta_R \omega_{\text{BX}}}{{U_{\text{BX}}}^2 (4\pi)^4}} \tag{1}$$

Where $P_T = 40$ W – transmitter power,

$G_T = 18$ dBi $= 63{,}1$ – transmitting antenna gain,

$G_R = 2$ – receiving antenna gain,

$\eta_T, \eta_R = 0.9$ efficiency coefficients of power transmission systems from the transmitter to the transmitting antenna and from the receiving antenna to the receiver,

$\omega_{\text{BX}} = 75\ \Omega$ – input impedance of the receiver

$U_{\text{BX}} = 0.7$ mV – receiver sensitivity (mobile terminal),

$k_0 = 0{,}05$ – energy absorption coefficient of incident waves by the reflecting surface.;

λ – wavelength equal to $\lambda = c/F$, where $c = 3{*}10^8$ – light speed;

$F = 5$ GHz – the frequency at which the signal is transmitted.

Using the MATLAB modeling environment, it is possible to calculate $\mathbf{R_1}$ and $\mathbf{R_2}$.

The following calculations for 5 GHz are obtained:

$R_1 = 999$ m,

$R_2 = 4$ m.

And the following calculations for 2.4 GHz are obtained:

$R_1 = 999$ m,

$R_2 = 17$ m.

When calculating $\mathbf{R_1}$ and $\mathbf{R_2}$, it becomes apparent that the assumption that area around the receiver, which is essential for reflecting the beams, is not a circle. This area is an oval, “compressed” from the side most distant from the point $\mathbf{A_1}$, and “elongated” from the side closest to the appearance **A**, Fig. 2. Such an oval is called Cassini oval (Fig. 2) [9].

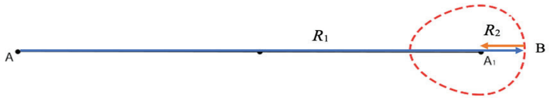

Fig. 2. "Transformation" of the shape of the area critical for reflection on the interval A_1 - A_2 from a "circle" to an oval.

When the distance between the base stations is very small, only the direct beam reaches the receiver. But as the distance increases, there are more obstacles in the path of the beam and more factors for its reflection. Thus, multipath conditions arise that destroy the useful signal [10].

If the reflected beam arrives after the registration of the symbol transmitted from the base station, then it is superimposed on the neighboring symbol and absorbs it. The higher the signal transmission rate, the shorter the useful signal pulse, and the more difficult it is for a positive signal to prove itself (Fig. 3) [11].

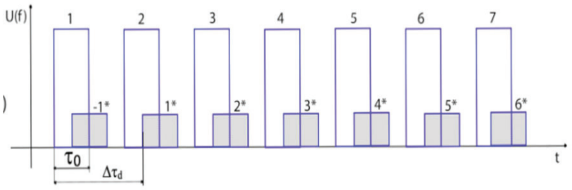

Fig. 3. Timing diagrams of pulses of the main signals and their responses that come to the receiver

Then, having spatial characteristics in a particular channel, the calculation of temporal characteristics may be proceeded. It means that the maximum response delay time will be calculated. As shown in Fig. 2, the maximum response will be delayed if ray goes from **A** to **A₁**, reaches the boundary of the designated area, reflects from point **B**, and only then gets to the receiver.

The time graph (Fig. 3) shows that the pulse response is being late and arrives at the receiver, superimposed on the original pulse, forming a delay time $\Delta\tau_d$, while the duration of the pulse itself is τ_0 (2):

$$\tau_0 = 1/v_0 , \qquad (2)$$

where v_0 – is the symbol rate.

Rates v_0 = 10 Mbit/s corresponds to τ_0 = 0.1 µs. Then $\Delta\tau_d$ will be calculated (3):

$$\Delta\tau_d = \Delta r/c^* \qquad (3)$$

where Δr is the difference between the length of the paths that the direct and reflected signals pass through;

c^* – speed of light.

The next step is to compare the results. Table 1 presents the results of calculations of the distance that the response passes before reaching the receiver and its delay time for the particular case shown in Fig. 2. The calculations are made for frequencies of 5 GHz and 2.4 GHz.

Table 1. Comparison of the results of calculations of the pulse transmission rate for various frequency ranges

Frequency range – *F*	The duration of the delay path – *Δr*, m	Maximum Response Delay – *Δτ_d*, µs
5 GHz	8.1	0.03
2.4 GHz	35.6	0.12

Evaluation of the signal-to-noise ratio for a communication channel with multipath, for the usage of 5 GHz and 2.4 GHz frequencies

Having spatial characteristics, i.e. a specific area that is significant for re-reflected signals, it became possible to calculate not only the response delay time, but also the total power of all interference within this area.

To do this, consider Fig. 4. It shows the same communication channel **A - A₁**. In this figure, the response passes a distance ρ from the transmitter (point **A**) and is reflected from some surface at point **C**. Then the response passes the path ρ' and hits the receiver **A₁**. The figure also shows the radii of the Cassini ovals: **R₁** and **R₂**.

Based on Fig. 4, it is possible to draw up a formula for calculating the total interference power $P_{n.max}$ (4):

$$P_{N.max} = \frac{2P_T G_T(\lambda)^2}{(4\pi)^2} * \left(\int_{R-R_2''}^{R-\Delta}\int_0^{\sqrt{\sqrt{a^4+4c^2(x-c)^2}-(x-c)^2-c^2}} \frac{1}{(x^2+y^2)[(R-x)^2+y^2]}\,dx\,dy + \int_{R-\Delta}^{R+\Delta}\int_0^{\sqrt{\sqrt{a^4+4c^2(x-c)^2}-(x-c)^2-c^2}} \frac{1}{(x^2+y^2)[(R-x)^2+y^2]}\,dx\,dy + \int_{R+\Delta}^{R+R_2'}\int_0^{\sqrt{\sqrt{a^4+4c^2(x-c)^2}-(x-c)^2-c^2}} \frac{1}{(x^2+y^2)[(R-x)^2+y^2]}\,dx\,dy\right) \qquad (4)$$

Where R = 1000 m is the distance from the transmitting to the receiving antenna.

Limit on the x-axis from $R - R_2''$ to $R + R_2'$, and on the y-axis from 0 to $y = \sqrt{\sqrt{a^4 + 4c^2(x-c)^2} - (x-c)^2 - c^2}$ (provided that the origin at point **A** is the center of the second Cassini oval) (Fig. 4).

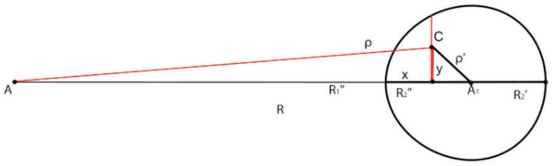

Fig.4. The delay in the response of the signal in the receiver, provided that the original signal is stretched n times

Using the MATLAB modeling environment, (4) will be calculated.

$P_{n.max}$ = 0.07 µW at the used frequency of 5 GHz;

$P_{n.max}$ = 0.5 µW at the used frequency of 2.4 GHz.

The useful signal power will be calculated using (5):

$$P_S = \frac{P_T G_T G_R \lambda^2}{(4\pi R)^2} \quad (5)$$

Results of calculation:
P_S = 0.12 μW at the used frequency of 5 GHz;
P_S = 2.6 μW at the used frequency of 2.4 GHz.
Table 1 provides a comparison of the obtained results of calculating the powers of the useful signal and the total interference power in the channel.

Table 1. Comparison of the results of calculations of the useful signal power and the power of interference for communication channels in the range of 5Hz and 2.4GHz

Frequency range – F, GHz	Power of the useful signal – P_S, μW	Cumulative Interference Power – P_S, μW
5	0.12	0.07
2.4	2.6	0.5

Next, it is needed to estimate the effect of multipath on the quality of communication in the radio link. To do this, it is necessary to compare the signal-to-noise ratio for both frequencies (2.4 GHz and 5 GHz), provided that there is no multipath in the communication channel and when communication is affected by multipath.

To begin with, it is necessary to calculate the signal-to-noise ratio (i.e. h^2) provided that there is no multipath in the channel (6) [12].

$$h^2 = \frac{P_s}{N_0 \Delta F} \quad (6)$$

Where P_s – power of the useful signal
N_0 – noise spectral power, 1.15*10^{-15}
ΔF – usable frequency band, 5 MHz or 2.4 MHz
Result:
h^2 = 20 at the used frequency of 5 GHz;
h^2 = 86,81 at the used frequency of 2.4 GHz.

Now it is necessary to calculate a new signal-to-noise ratio (i.e. h_n^2) provided that there is multipath in the channel (7).

$$h_n^2 = \frac{P_s}{N_0 \Delta F + P_{n.max}} \quad (7)$$

Where P_s – power of the useful signal
N_0 – noise spectral power, 1.15*10^{-15}
ΔF – usable frequency band, 5 MHz or 2.4 MHz
$P_{n.max}$ – Cumulative Interference Power.
Result:
h_n^2 = 1,58 at the used frequency of 5 GHz;
h_n^2 = 0.19 at the used frequency of 2.4 GHz.

Table 2 provides a comparison of the obtained signal-to-noise ratio results without multipath influence and with influence.

Table 2. Comparison of the results of calculations of signal-to-noise ratios (with and without the influence of multipath) for communication channels in the range of 5Hz and 2.4GHz

Frequency range – F, GHz	Signal-to-noise ratio provided that there is no multipath effect in the channel – h^2	Signal-to-noise ratio provided that there is multipath effect in the channel – h_n^2
5	20	1.58
2.4	86.81	0.19

Conclusions

1. A technique for spatial evaluations of the interference influence due to multipath on the quality of wireless communication is proposed.

2. The proposed model makes it possible to determine the effect of interference power in subbands traditionally assigned in IEEE 802.11xx technology, namely 2.4 GHz and 5 GHz.

3. As expected, the effects of interference due to multipath significantly reduce the quality of communication, such as:

- in the 5 GHz band, instead of h^2 = 20, h_n^2 = 1.58 is obtained;
- in the 2.4 GHz band, instead of h^2 = 86.81, h_n^2 = 0.19 is obtained;

Thus, it is shown that the effect of multipath is the less pronounced, the higher the frequency of the carrier radio link of wireless communication.

The frequency rating significantly affects the quality of communication in multipath conditions. In this case, lowering the frequency significantly improves the reception condition outside of multipath effect. However, it deteriorates significantly due to the effects of rays reflected from the Earth's surface.

In the considered case, the useful signal power in the 2.4 GHz band is 4.2 times higher; at the same time, the power of reflected interference is 19 times higher than in the 5 GHz band.

4. The proposed spatial model is the basis for determining the characteristics of the radio link in the OFDM mode, which is the subject of further research.

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Оцінка впливу багатопроміневості на якість радіозв'язку в технологічному діапазоні IEEE 802.11xx

Проблематика. В результаті відбиття променів від будівель, від поверхні Землі або від горизонтальних кордонів між різними шарами атмосфери виникають багатопроменеві ефекти, що викликають швидкі завмирання, що погіршує якість обслуговування.

Мета дослідження. Визначити вплив багатопроменеві на відношення сигнал/шум у бездротовому каналі зв'язку. Порівняти отримані результати каналу зв'язку на робочих частотах стандарту IEEE 802.11xx: 5 ГГц і 2,4 ГГц.

Методика реалізації. Розраховуються потужності корисного сигналу та сукупність потужностей перешкод для каналу зв'язку з багатопроменевістю. Порівнюється відношення сигнал/шум для такого каналу на робочих частотах 5 ГГц та 2,4 ГГц.

Результати дослідження. Результати дослідження показали, що дія багатопроменевості тим менше проявляється, чим вища частота несучої радіолінії бездротового зв'язку.

Номінал частоти суттєво впливає на якість зв'язку в умовах багатопроменевості. У цьому зниження частоти значно покращує умови прийому поза впливом багатопроменеві. Проте, істотно погіршується за умов дії відбитих від Землі променів.

У розглянутому випадку потужність корисного сигналу в діапазоні 2.4 ГГц в 42 рази вище; одночасно потужність відбитих перешкод у 19 разів більша порівняно з діапазоном 5 ГГц.

Висновки. Запропонована модель дозволяє визначити вплив потужності перешкод у діапазонах, що традиційно відводяться у технології IEEE 802.11xx, а саме 2,4 ГГц та 5 ГГц.

Ключові слова: *багатопроменевість; IEEE 802.11xx; овал Кассіні; OFDM; швидкі завмирання.*